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The Sewer Research Station in Frejlev

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Department of Civil Engineering
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Denmark

The Sewer Research Station in Frejlev



Annual Report - 2000

Kjeld Schaarup-Jensen and Thorkild Hvitved-Jacobsen
May 2004

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FRONT-PAGE PHOTO:

The Frejlev South rain gauge – located close to a waste water pump station (to the right of the gauge) and a retention basin (behind the gauge) in a residential and separately sewered part of the Frejlev catchment.

PREFACE

During late fall 1996 the sewer research and monitoring station in Frejlev was completed, jointly financed by Aalborg Municipality and Aalborg University. The year 1997 was used to get the rather new and complicated apparatus for rainfall, flow and water quality parameters including data transmission to Aalborg University in proper operation. This annual report for the year 2000 activities at the station in Frejlev is the third one issued. It is the objective not just to produce an annual overview for internal reasons but also to inform interested researchers and practitioners outside Aalborg Municipality and Aalborg University on the unique possibilities, which exist.

It is an important feature of the sewer monitoring station that dry as well as wet weather aspects can be dealt with. The ambition for Aalborg Municipality and Aalborg University is that the station will serve the dual purpose of being a site for the research on sewer systems and processes at the Department of Civil Engineering as well as a possibility for the establishment of continuous high quality time series of sewer related parameters, e.g. flow.

Only few - if any - sewer monitoring stations like the one in Frejlev exist. Without no doubt the field data produced - especially the time series - in the course of time will serve as a unique basis for projects dealing with the improvement of sewer design and performance. Several researchers and institutions outside Denmark have already visited the field station and shown their interests in the results obtained. To observe future needs for information on the station, it has therefore been decided to produce the annual report in English.

Aalborg, May 2004

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1. INTRODUCTION

During autumn 1996 a research and monitoring facility was constructed as a part of the intercepting sewer from Frejlev, a small town located 7 km Southwest of Aalborg, Denmark. The construction of this station was made possible due to an outstanding foresight from the Municipality of Aalborg, Denmark. Besides giving the permission for the installation of the necessary structures in the sewer system, the local authorities financially supported the project in co-operation with Aalborg University, Faculty of Engineering and Science.

Frejlev is a town with about 2000 inhabitants and without significant industries. The total catchment covers an area of 85 ha situated on a hillside which slopes down in a northern direction from an uphill level approximately 55 m above sea level to a downhill level 15 m above sea level. The catchment is mainly provided with combined sewers, figure 1.

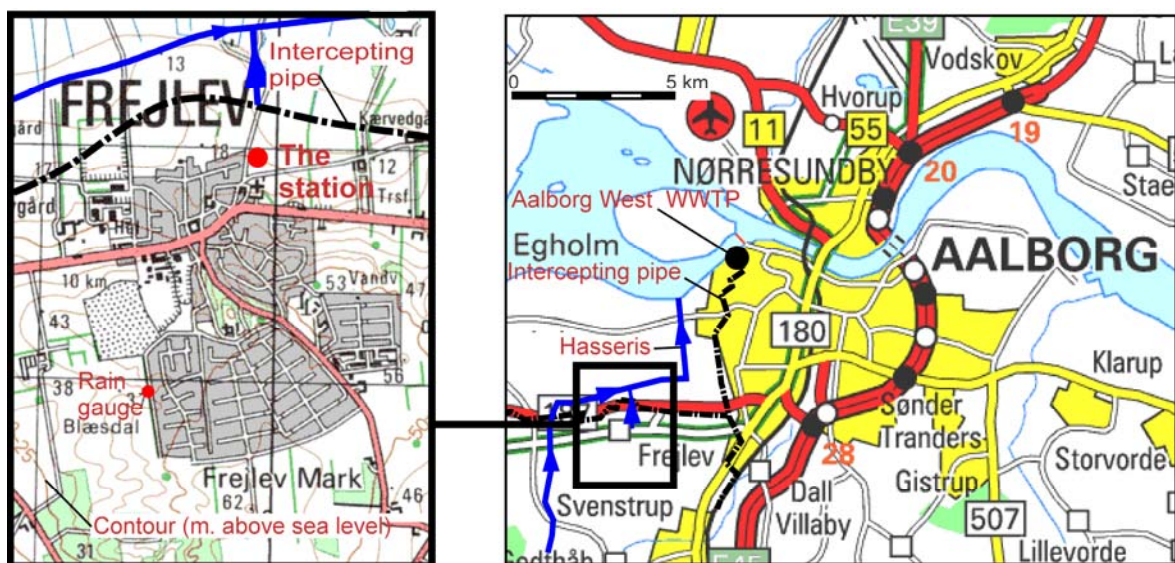


Figure 1 : Aalborg and the experimental site including the town of Frejlev, the Hasseris stream and the Aalborg West WWTP.

During dry weather conditions the wastewater flow is diverted to a wastewater treatment plant Aalborg West in a 300 mm diameter interceptor sewer starting in a combined sewer overflow (CSO) structure located downhill and about 500 m north of Frejlev. This CSO structure diverts the sewage from Frejlev in a 1000 mm diameter combined sewer. During wet weather conditions, CSO's are discharged into Hasseris stream, which flows into the Limfjord about 6 kilometres Northeast of Frejlev.

The long-term measurements in the station will comply with the objectives to create the basis of knowledge on e.g.:

- long term time series containing seasonal as well as diurnal variations in dry weather flow and concentrations of pollutants
- rainfall - runoff relationships,
- the distribution of storm water concentrations of relevant pollutants - including relationships of the level of concentration with rainfall as well as sewer system characteristics.

Furthermore, the measurements can form the basis of a better understanding of transport and transformations of particulate and soluble pollutants in combined sewers including suspended and bed load characteristics and information on processes like sedimentation, resuspension and microbial transformations (Hvitved-Jacobsen et al., 1997; Schlütter and Schaarup-Jensen, 1997; Tanaka and Hvitved-Jacobsen, 1997; Vollertsen and Hvitved-Jacobsen, 1997).

In addition, the variability of urban runoff and wastewater flow parameters as well as quality characteristics is known to be significant and often the standard deviation of a quality parameter is of the same order of magnitude as the corresponding mean value, (Johansen, 1985; Harremoës, 1988; Hvitved-Jacobsen and Yousef, 1991; House et al., 1993). It is evident that design and operation of sewer systems and their interactions with the entire urban wastewater system, i.e. wastewater treatment plants (WWTPs) and local receiving waters, is highly dependant on a detailed knowledge of this variability.

In publications on sewer system measurements, dry weather flow seems to hold a secondary position compared to wet weather flow. In many ways this is surprising because pollutant loads and quality variations during dry weather conditions are important for operation and maintenance of the sewer system itself as well as for the WWTP. Furthermore, only through continuous measurements during dry weather conditions it will be possible to identify if a sewer has a poor or a good natural purification capacity and measurements are necessary to understand why this is (or is not) the case. This knowledge is - due to resuspension of pollutants settled during dry weather conditions - crucial to the determination of pollutant loads which during wet weather are diverted to either WWTPs or discharged into receiving waters via a CSO structure. It is therefore concluded that long term high quality measurements during both dry and wet weather conditions are important to obtain a better understanding of transport and transformation of pollutants in sewer systems.

Concerning the applicability of future water quality and hydraulic time series from Frejlev, it will not be possible to make general conclusions until similar measurements are performed elsewhere. The need of doing so is evident and will become more and more required concurrently with the appearance of more and more complicated numerical computer models capable of simulating flow as well as transport and transformation of pollutants in sewer systems, WWTP and receiving waters. Vital for the reliability of simulations with such models are a number of conditions, e.g. the mathematical model, the (numerical) method of simulation and the degree of knowledge of the system to be simulated. In case of sewer systems this includes knowledge of local time series for a number of model input and/or output parameters in order to perform a model calibration and validation before any further use of the model is possible. Omitting the model calibration and validation process and just finding values of parameters in the scientific literature can typically only provide the user of the model with some general and perhaps misleading simulation results

2. THE STATION

2.1 OVERVIEW OF THE SYSTEM

On average the 2000 inhabitants in Frejlev produce 4-5 l/s of wastewater. Rather sporadic flow measurements in the Frejlev sewer indicate that no infiltration from groundwater aquifers takes place and the dry weather flow is expected to have a diurnal variation between 0 and approximately 10 l/s. During wet weather, a 85 ha catchment with a reduced area of approximately 30 ha and a time of concentration of 20 min will produce a maximum flow of 3800 l/s according to the rational method and a rainfall intensity of 128 l/(ha·s) which in Denmark appears with a return period of 5 year on average. From the very beginning it was an indispensable requirement that dry weather flow as well as wet weather flow at a reasonable limit (return period of 5-10 years) could be recorded by the flow monitoring equipment. This meant that this equipment should have a capacity of performing high quality flow measurements of the interval of 0-3800 l/s

As no commercial available flow meter today has the capacity of producing high quality flow measurements within such an interval, it became clear that the original single pipe stretch of the sewer had to be divided into 2: a 300 mm diameter 'dry weather pipe' and a 1000 mm diameter 'wet weather pipe'. This basic demand determined the design concept, figure 2.

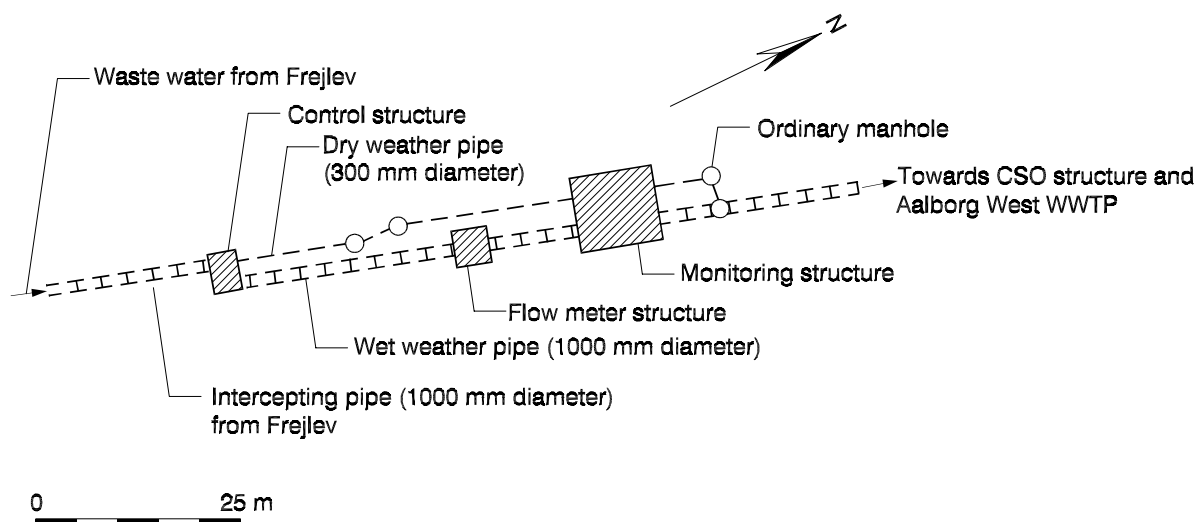


Figure 2: The research and monitoring station upstream the CSO structure of the Frejlev sewer system interceptor.

In order to control in which pipe the flow should take place, the monitoring stretch is equipped with a control structure having a sliding gate which will close the inlet to the small pipe when the flow due to e.g. rainfall runoff is higher than a predetermined value, figure 3. In this way mixed wastewater and runoff water is diverted to the big pipe. When the flow in this pipe is reduced to a certain value, the opposite procedure will take place. This means that future rainfall runoff hydrographs must be formed based on a superposition technique.

2.1 THE FLOW MEASUREMENT SYSTEMS

The dry and the wet weather pipes are equipped with high quality electromagnetic flow meters of the Parti-Mag type manufactured by Bailey-Fischer and Porter. According to technical speci-

cations, these two flow meters are able to produce high quality flow measurements in the intervals 1-700 l/s for the small pipe and 50-7800 l/s for the big pipe with a maximum flow rate error of 1-1.5% of rating. The flow meter supplier has specified a simple set of installation requirements demanding a straight pipe section without any hydraulic disturbances within a distance to a flow meter of 15 times the diameter - distributed with 10 and 5 times the diameter in upstream and downstream directions, respectively. For this reason the wet weather flow meter has been placed in its own structure, figure 2 and figure 4.

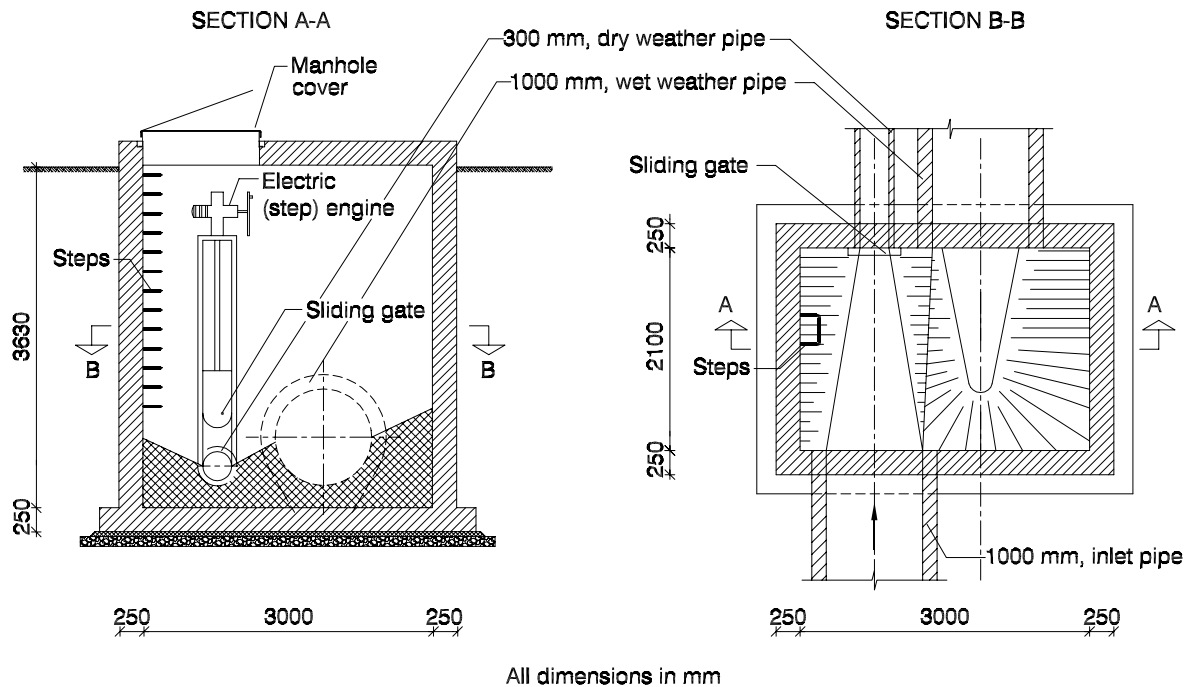


Figure 3: Control structure, upper end of measurement system stretch.

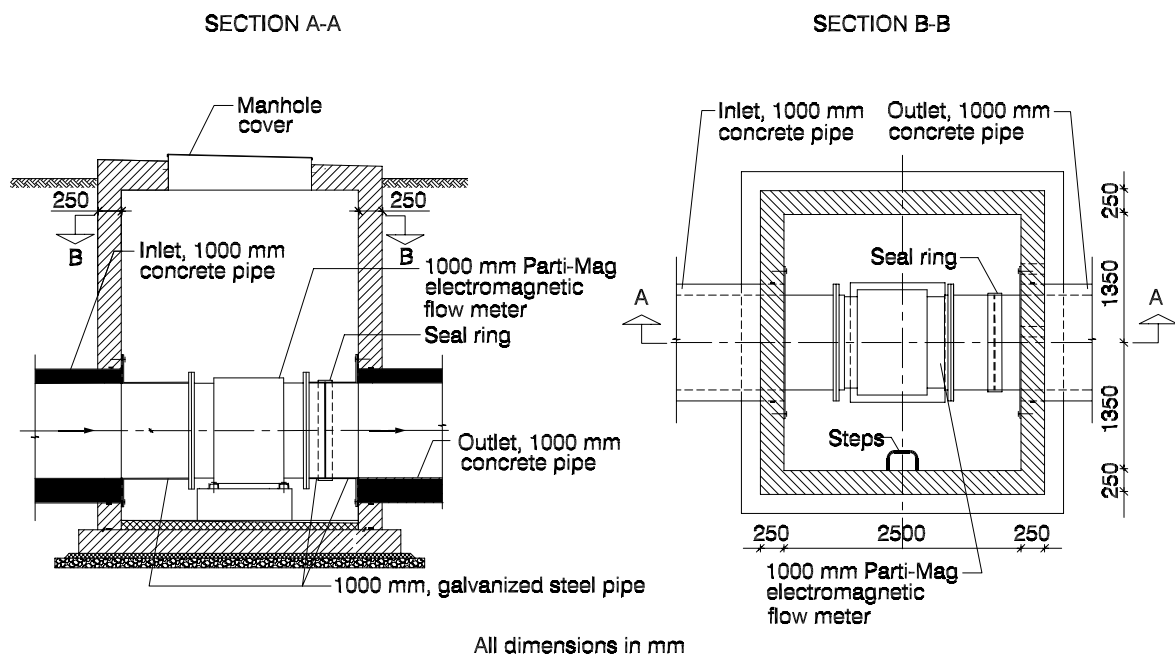


Figure 4: Electromagnetic 1000 mm diameter flow meter placed in a separate structure.

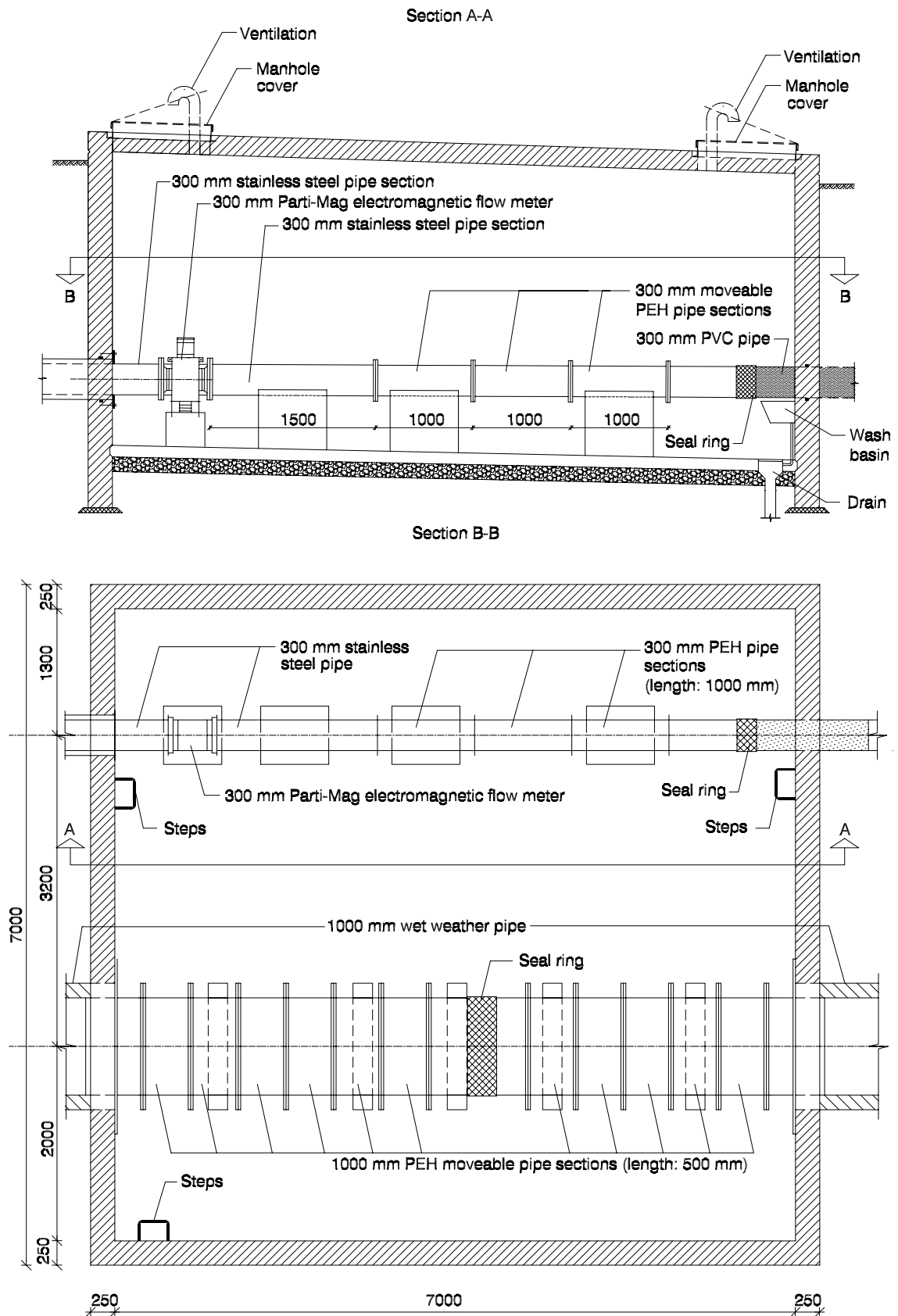


Figure 5: The monitoring structure.

The small pipe flow meter is placed in the monitoring structure itself, figure 5, as a 'hydraulics safety zone' of only 1.5 m was needed in the downstream direction at this flow meter, leaving enough space for other measurement arrangements. From the control structure down to the monitoring structure, all pipes are made of concrete. In order to have manually removable pipe sections within the monitoring structure, polyethylene (PEH) was chosen as pipe material. The length of each section is 1 and 0.5 m for the small and the big pipe, respectively. For the big pipe sections, this results in a weight of approximately 50 kg, which can be relatively easily handled.

2.3 MEASUREMENT SYSTEMS FOR WASTEWATER AND STORMWATER QUALITY

In addition to the flow meters, the monitoring station is equipped with water samplers and sensors for measurements of wastewater quality parameters depending on actual needs. Sampling for analysis of wastewater components and parameters will be carried out depending on specific research project requirements or performed according to specific defined procedures in case of e.g. expected extreme runoff events. Furthermore, growth of biofilms for analysis or laboratory investigations is possible at the surface of the PEH sections of the sewer pipes and experiments on e.g. sediment microbial processes and resuspension of sewer sediments can be carried out using silt traps. The dry weather pipe is equipped with a device that allows it to operate separately with a waste water outflow from the pipe of approximately 1 l/s. This device makes it possible to perform experiments that require a continuous inflow of fresh wastewater.

2.4. SUPPLEMENTARY EQUIPMENT

On the 'roof' of the measurement structure an automatic rain gauge station (Frejlev North) is placed which in addition to a rain gauge at the uphill part of Frejlev (Frejlev South) have become a part of the national rain gauge system managed by the Danish Waste Water Control Committee and operated by the Danish Meteorological Institute (DMI). Data from the rain gauge at the monitoring station will become a part of the total set of data transmitted to Aalborg University, Department of Civil Engineering, as an almost continuous time series. Data from the second rain gauge will be accessible via DMI.

In order to ensure efficient transmission of data, the monitoring station is equipped with 2 mobile and wireless radio stations each capable of transmitting - as VHF signals - 5 analogous and 8 digital data signals to a receiver station set-up at the university campus. From this main station, the 10 analogous and 16 digital data channels can be monitored continuously. Furthermore, the data transmission system works as a small scale real time processing unit and a digital signal can be transmitted to the monitoring station, e.g. in order to start a pump or a water sampler. All data series are stored on a PC connected to the main station at the university campus. From here data can be stored on a long-term basis on CD-ROM disks.

3. MEASUREMENTS IN 2000

3.1 RAINFALL MEASUREMENTS

During 2000 the rain gauges in Frejlev, Frejlev South and Frejlev North, have been working with outfall periods which amount to 4.4 and 0.6% of the time, respectively (Nielsen, 2001). The outfall periods for the Frejlev South gauge are located in February and March amounting to 29 and 353 hours, respectively. Looking at monthly precipitation values of 2000 – see figure 6 below – this spring calamity is very conspicuous, whereas a rather big difference in the precipitation values of June not has been apprehended as a dropout of the gauge procedure at one of the 2 stations.

As a standard of reference figure 6 also holds the monthly mean values (1961-1990) from the DMI rain gauge station in Tylstrup (Frich et al., 1997), 15 kilometres North of Aalborg. According to Frich et al. the mean annual precipitation in Tylstrup and Frejlev is of the same order of magnitude, 650 mm.

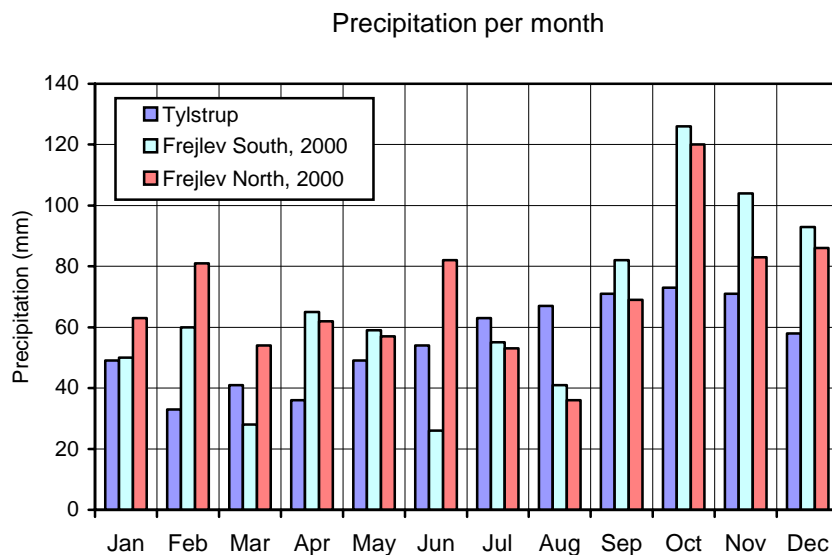


Figure 6: Precipitation per month measured at Tylstrup (mean, 1961-1990), Frejlev North and Frejlev South (2000).

The 2000 annual precipitation at the Frejlev South and North rain gauges were 789 mm and 845 mm, respectively – cf. figure 7.

From figures 6 and 7 it is evident that 2000 - as is the case with both 1998 and 1999 - can be characterized as a “wet year” due to large quantities of rain in all months except July and August.

Considering the above mentioned outfall periods which mainly have affected the Frejlev South gauge, the annual precipitation of this station may very well be as big as the Frejlev North – maybe even bigger. If this evaluation is correct, the 2000 annual precipitation value at the southern station again has exceeded the northern station value – but contrary to 1998 and 1999 perhaps only to a small extent, see figure 7.

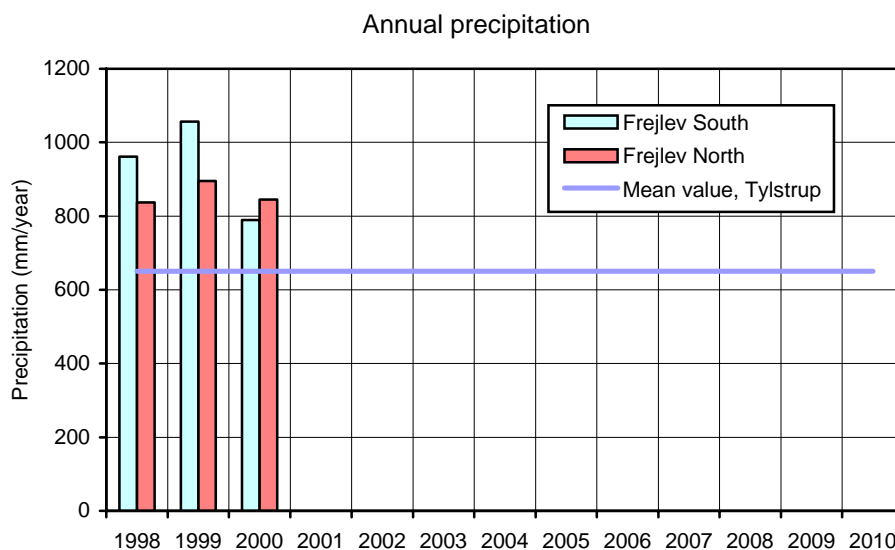


Figure 7: Annual measured precipitation, Frejlev North and South, 1998-2000, compared to Tylstrup mean value, 1961-1990.

In total 237 and 267 rainfall events have been recorded by the 2 rain gauges in Frejlev during 2000. In the 1999 annual report 303 rainfall events recorded at the Frejlev South rain gauge station was analyzed in order to describe the rain depth distribution.

Another interesting aspect related to historical rainfall data series is the time between start of rainfall events. For this purpose the Frejlev North rainfall data of 2000 have been analyzed in order to uncover the distribution of this rainfall parameter for one specific year – cf. figure 8:

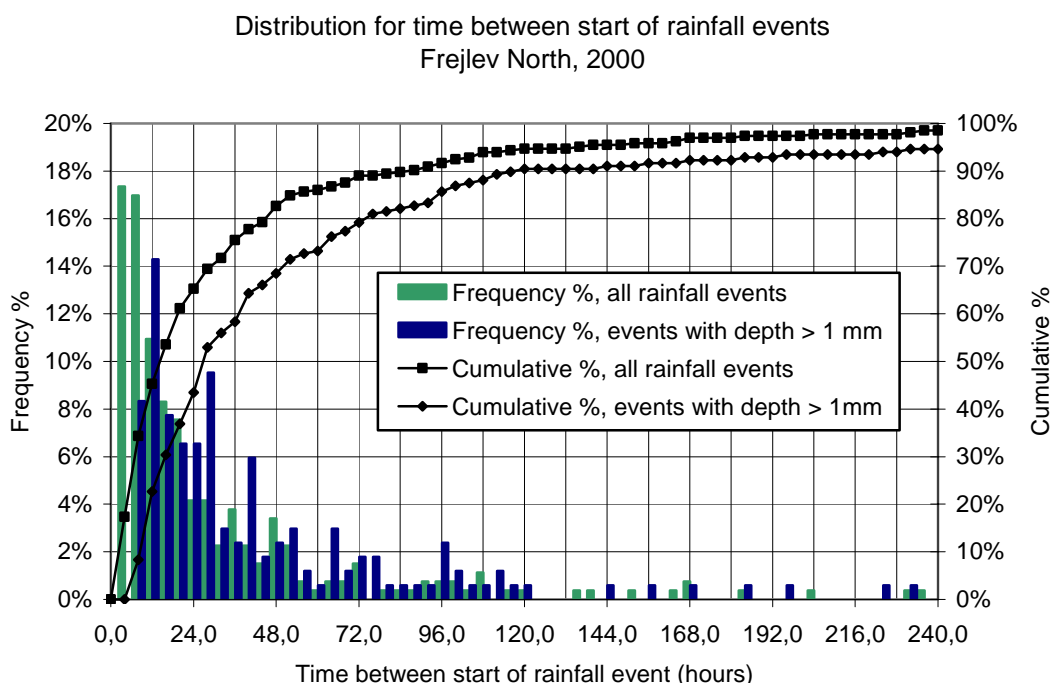


Figure 8: Distribution for time between start of rainfall event, Frejlev North, 2000.

From this analysis it appears that the mean value of time between the start of 2 succeeding rainfall events in 2000 amounted to 33 hours. The median value – see fig. 8 - is somewhat smaller - approximately 14 hours.

Due to an initial loss in surface flow only rainfall events of a certain rain depth – in Denmark normally greater than 0.5-1 mm - will produce inflow of storm water to the sewer system. Owing to this fact, the above mentioned analysis has also included the time between 2 succeeding rainfall events - both with a rain depth greater than 1 mm. It appears that 166 events from the Frejlev South gauge can meet this demand, indicating that 100 rainfall events – according to approx. 40% - in 2000 from the same gauge have a rainfall depth smaller than 1 mm. From the analysis as well as fig. 8, mean and median values for such rainfall events has been found to amount to 52 and 22 hours, respectively.

From this fact it can be concluded that storm water in 2000 has been discharged to the Frejlev sewer system approximately every second day – in average.

This information could be of some importance for combined sewer systems depending on the self cleaning capacity of the system during dry weather conditions. For systems with a poor self cleaning capacity during dry weather conditions the overall self cleaning capacity will – to a high degree – depend on the cleaning capacity of the storm water pipe flow caused by rainfall events.

In Frejlev the average time between start of 2 succeeding rainfall events with rain depths greater than 1 mm is approx. 48 hours as mentioned above. However, this information shall be supplemented by a look at fig. 8 illustrating that long dry weather periods do occur. E.g. 10% of the rainfall events capable of generating storm water to the sewer system have a time between start of event of more than 120 hours, corresponding to a dry weather flow period of nearly same length.

3.2 FLOW MEASUREMENTS

After new-calibration the flow meters were reinstalled in Frejlev in August 1998 and since early September 1998 the two meters have been working satisfactory according to the specifications.

As mentioned above approx. 270 rainfall events have occurred in 2000 on the Frejlev sewer catchments and it is estimated that approx. 60% of these events have generated surface runoff of storm water discharged from the catchments to the Frejlev sewer system. Most likely flows generated by these rainfall events - together with the dry weather waste water flow – have been successfully recorded by the 2 flow meters. But unfortunately only a minor part of these data has been transmitted to the flow database at Aalborg University due to heavy problems with the data transmission equipment. In total the flow database outfall period in 2000 amounts to 70%, which in plain language only can be characterized as being most unsatisfactory.

Due to this unfortunate fact it has been impossible to expose the flow measurements of 2000 to any qualified analyses.

3.3 WATER QUALITY MEASUREMENTS AND SAMPLING

The Frejlev sewer monitoring station is designed for sampling of wastewater, in-line measurements of wastewater quality parameters and pilot scale experiments that require continuous inflow of fresh wastewater. These measurements can be performed during both dry and wet weather flow conditions. In this respect, installations and conditions for sampling and measurements can be flexible arranged to comply with specific and varying demands.

The monitoring station makes it possible to take dry weather wastewater samples for laboratory studies under rather well defined conditions in terms of flow and expected activity level in the catchment area of Frejlev. Therefore, wastewater samples from Frejlev are generally applied of both student and researchers in environmental engineering when “young” wastewater is needed for laboratory experiments. The reference list for year 2000 includes results that - at least to some extent - are based on wastewater samples from the monitoring station.

In particular, the following two research projects have in 2000 been performed in the Frejlev sewer monitoring station:

- **Exfiltration from sewer networks**

This research project was financially supported by the Danish Environmental Protection Agency (Miljøstyrelsen). The project was during the period 2000-2001 performed by the Environmental Engineering Laboratory of the department.

- **Organic micro pollutants in combined sewer overflows (CSOs)**

This research project is a part of the nation-wide program (NOVA 2003) for monitoring of surface water and groundwater pollution. The project is financially supported by the Danish Environmental Protection Agency (Miljøstyrelsen). The project was during the period 1999-2001 experimentally performed by the County of Northern Jutland.

The two projects will be further described in the 2001 edition of this report series.

4. EQUIPMENT SPECIFICATIONS

Rain:	<p><u>On top of monitoring structure (Frejlev North)</u></p> <p>A tipping bucket rain gauge, bucket capacity: 0.2 mm, produced by Rimco Australia. This gauge (no.: 20458) forms a part of a nation wide rain gauge system operated by the Danish Meteorological Institute on behalf of The Water Pollution Committee of The Society of Danish Engineers.</p> <p><u>In the southern part of Frejlev (Frejlev South)</u></p> <p>A tipping bucket rain gauge, bucket capacity: 0.2 mm, produced by Rimco Australia. This gauge (no.: 20456) forms a part of a nation wide rain gauge system operated by the Danish Meteorological Institute on behalf of The Water Pollution Committee of The Society of Danish Engineers.</p>
Flow:	<p><u>In monitoring structure</u></p> <p>Electromagnetic flow meter, Parti-Mag II, model DP 4_F, diameter size: 300 mm. Produced by Bailey Fischer & Porter, Göttingen, Germany, 1996, equipment number: A1 9606.</p> <p><u>In flow meter structure</u></p> <p>Electromagnetic flow meter, Parti-Mag II, model DP 4_F, diameter size: 1000 mm. Produced by Bailey Fischer & Porter, Göttingen, Germany, 1996, equipment number: A2 9606.</p>
Water quality:	<p><u>In control structure and monitoring structure</u></p> <p>Non-stationary sampling, monitoring equipment and reactors for specific project purposes.</p>
Data transmission:	<p><u>In monitoring structure</u></p> <p>2 measurement radio stations (8 bit) with 5 analog channels, 8 input and 8 output digital channels, produced by Teletronic, Copenhagen Research Center, Denmark.</p> <p><u>Aalborg University, Sohngaardsholmsvej 57, Aalborg</u></p> <p>1 main 8 bit radio station for max. 64 measurement stations, min. 12 kilometers reach, produced by Teletronic, Copenhagen Research Center, Denmark.</p>

5. EXTRACTION OF DATA FROM DATABASE

The measurements in the Frejlev station of rainfall and flow data has been placed as time series in a database at the Department of Civil Engineering, Aalborg University. Till now this database do not contain any water quality data at all – cf. section 3.3. At present it is not decided if water quality data shall be a part of the rainfall-flow database due to natural differences in dataformat between these 2 types of data. It might therefore be decided to form 2 databases for these 2 data types or time series of which the rainfall-flow time series is continuous while the water quality time series will be discontinuous due to limited resources.

The owners of the station have decided that this (these) database(s) shall be accessible to the general public for payment. For the cost price data can be extracted from the database(s) to a CD-ROM disk together with a post-processing program.

Application for extraction of data must be passed to:

Assoc. Prof. Kjeld Schaarup-Jensen,
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6. PUBLICATIONS OF 2000 RELATED TO THE STATION

The annual reports of 1998 and 1999 contains an up-to-date list of publications produced at the Department of Civil Engineering including results based on data performed at the Frejlev sewer research and monitoring station.

However, the authors of the annual reports have realized that such an adding up up-to-date list of publications rapidly will become very voluminous. For this reason the authors have decided to leave this concept of an up-to-date list of publications in favour of a list of publications related to the year of the annual report.

In future, readers of the annual reports - wanting to have a general overview of all publications related to the station - will have to make their own "summary" by looking up this chapter in each annual report.

According to this the following list of publications are all solely related to the year of 2000 - apart from the first one, which has been chosen to be contained in each annual report due to its fundamental character.

Schaarup-Jensen, K., Thorkild Hvitved-Jacobsen, Bent Jütte, Bjarne Nielsen and Tage Pedersen (1998). A Danish Sewer Research and Monitoring Station, *Water Science and Technology*, vol. 37, no. 1, 197-204.

Vollertsen, J. and T. Hvitved-Jacobsen (2000), Sewer quality modeling – a dry weather approach, *Urban Water*, 2(2), 295-303.

Tanaka, N., T. Hvitved-Jacobsen, T. Ochi and N. Sato (2000), Aerobic-anaerobic microbial wastewater transformations and reaeration in an air-injected pressure sewer, *Water Environment Research*, 72(6), 665-674.

Tanaka, N., T. Hvitved-Jacobsen and T. Horie (2000), Transformations of carbon and sulfur wastewater components under aerobic-anaerobic transient conditions in sewer systems, *Water Environment Research*, 72(6), 651-664.

Vollertsen, J. and T. Hvitved-Jacobsen (2000), Resuspension and oxygen uptake of sediments in combined sewers, *Urban Water*, 2(1), 21-27.

Arnbjerg-Nielsen, K., T. Hvitved-Jacobsen, N.B. Johansen, P.S. Mikkelsen, B.K. Poulsen, W. Rauch og F. Schlütter (2000), Stofkoncentrationer i regnbetingede udledninger fra fællessystemer (Pollutant concentrations in runoff from combined sewer catchments), Miljøprojekt nr. 532, Miljøstyrelsen (National Agency of Environmental Protection), pp 127.

Hvitved-Jacobsen, T. and J. Vollertsen (2000), Formation modeling of odours in sewer networks, 1st International Meeting on Odour Measurement and Modelling, Cranfield University, Bedford, UK, May 31, 2000, pp 10.

Hvitved-Jacobsen, T., J. Vollertsen and N. Tanaka (2000), An integrated aerobic/anaerobic approach for prediction of sulfide formation in sewers, *Water Science & Technology*, vol. 41, no. 6, 107-116.

Abdul-Talib, S., Z. Ujang, T. Hvitved-Jacobsen and J. Vollertsen (2000), Laboratory procedure for oxygen utilization rate in characterizing municipal wastewater, Proceedings of the 6th International Conference on Pollution Control in Metropolitan Cities (POLMET),

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Abdul-Talib, S., Z. Ujang and T. Hvitved-Jacobsen (2000), Sewer design: a shift from the conventional view, Proceedings of the 6th International Conference on Pollution Control in Metropolitan Cities (POLMET), Kuala Lumpur, Malaysia, March 20-23, 2000, pp 14.

Abdul-Talib, S., Z. Ujang and T. Hvitved-Jacobsen (2000), Characterization of wastewater in sewer in hot-climate countries using OUR, Proceedings of COE Symposium on Establishment and Evaluation of Advanced Wastewater Treatment Technology Systems using functions of Complex Microbial Community, Tokyo, Japan, March 6-8, 2000, pp2.

Tanaka, N. and T. Hvitved-Jacobsen (2000), Sulfide production and wastewater quality - investigations in a pilot plant pressure sewer, Proceedings from the 1st World Congress of the International Water Association (IWA), Paris, France, July 3-7, 2000, vol. 5, 192-199.

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